N95- 23638

ADVANCED MULTI-PHASE FLOW CFD MODEL DEVELOPMENT FOR SOLID ROCKET MOTOR FLOWFIELD ANALYSIS*

Paul Liaw, Y.S. Chen, and H. M. Shang
Engineering Sciences, Inc.
Huntsville, AL

D. Doran
ED 32, NASA Marshall Space Flight Center

p. 26

ABSTRACT

It is known that the simulations of solid rocket motor internal flow field with AL-based propellants require complex multi-phase turbulent flow model. The objective of this study is to develop an advanced particulate multi-phase flow model which includes the effects of particle dynamics, chemical reaction and hot gas flow turbulence. The inclusion of particle agglomeration, particle/gas reaction and mass transfer, particle collision, coalescence and breakup mechanisms in modeling the particle dynamics will allow the proposed model to realistically simulate the flowfield inside a solid rocket motor.

The Finite Difference Navier-Stokes numerical code FDNS is used to simulate the steady-state multi-phase particulate flow field for a 3-zone 2-D axisymmetric ASRM model and a 6-zone 3-D ASRM model at launch conditions. The 2-D model includes aft-end cavity and submerged nozzle. The 3-D model represents the whole ASRM geometry, including additional grain port area in the gas cavity and two inhibitors.

FDNS is a pressure based finite difference Navier-Stokes flow solver with time-accurate adaptive second-order upwind schemes, standard and extended k-ε models with compressibility corrections, multi-zone body-fitted formulations, and turbulence/particle interaction model. Eulerian/Lagrangian multi-phase solution method is applied for multi-zone mesh. To simulate the chemical reaction, penalty function corrected efficient finite-rate chemistry integration method is used in FDNS. For the AL particle combustion rate, the Hermsen correlation is employed. To simulate the turbulent dispersion of particles, the Gaussian probability distribution with standard deviation equal to $(2k/3)^{1/2}$ is used for the random turbulent velocity components.

The flow field in the aft-end cavity of the ASRM is analyzed to investigate its significant impact on the operation of the motor as well as its performance. It is known that heat flux and the pressure distributions in this region will cause recirculation and influence the design requirements. Chemical reaction of gas flow is a factor affecting the performance of the ASRM. An accurate analysis for chemically reacting flow is therefore important in the design of the ASRM. Twelve gas elements (H_2O, O_2, H_2, O, H, OH, CO, CO_2, CL, CL_2, HCL, and N_2) were considered for the chemical reaction in present study. For multi-phase calculations, the particulate phase was injected at the propellant grain surface. The particulate phase was assumed to be aluminum oxide (Al_2O_3) only. The mass fraction of the particulate phase was assumed to be 53% of the mixture.

The computational results reveal that the flow field near the juncture of aft-end cavity and the submerged nozzle is very complex. The effects of the turbulent particles affect the flow field significantly and provide better prediction of the ASRM performance. The multi-phase flow analysis using the FDNS code in the present research can be used as a design tool for solid rocket motor applications.

* This work is supported by NASA Marshall Space Flight Center under Contract NAS8-39398.

PAGE 524 INTENTIONALLY BLANK

PRECEDING PAGE BLANK NOT FILMED

ADVANCED MULTI-PHASE FLOW CFD MODEL DEVELOPMENT FOR SOLID ROCKET MOTOR FLOWFIELD ANALYSIS

Paul Liaw, Y. S. Chen, and H. M. Shang
Engineering Sciences, Inc.

D. Doran
ED32, NASA Marshall Space Flight Center

11th Workshop for CFD Applications in Rocket Propulsion

April 20-22, 1993

ESI Engineering Sciences, Inc.

OBJECTIVE

1. BACKGROUND AND GENERAL APPROACH
2. NUMERICAL METHOD
3. ASRM APPLICATION --- CURRENT STATUS
4. CONCLUSIONS
5. FOLLOWING WORK

BACKGROUND & GENERAL APPROACH

- SIMULATIONS OF SOLID ROCKET MOTOR INTERNAL FLOW FIELD WITH AL-BASED PROPELLANTS REQUIRE COMPLEX MULTI-PHASE TURBULENT FLOW MODEL

- CRUCIAL FACTORS SUCH AS THE PARTICLE SIZE DISTRIBUTIONS AND PARTICLE COMBUSTION INSIDE THE MOTOR ARE IMPORTANT FOR CORRECT DESCRIPTION OF THE FLOW FIELD AND GOOD PREDICTION OF THE MOTOR PERFORMANCE

- SOME EXPERIMENTAL DATA EXIST FOR AL-AGGLOMERATES NEAR THE AP/HTPB/AL PROPELLANT WHICH CAN BE USED TO GENERATE INITIAL PARTICLE SIZES
- PARTICLE TRACKING METHODOLOGY WITH COMBUSTION MODEL IN TURBULENT HOT GAS SHALL BE EMPLOYED TO DESCRIBE THE PARTICLE BURNING AND SIZE REDISTRIBUTION HISTORY INSIDE THE MOTOR
- EXISTING MOTOR NOZZLE EXIT MEAN PARTICLE SIZE CORRELATION, D43, CAN BE USED TO ANCHOR THE MODEL PREDICTIONS

ESI Engineering Sciences, Inc.

NUMERICAL METHOD

- PRESSURE BASED FINITE DIFFERENCE NAVIER-STOKES FLOW SOLVER (FDNS)
- TIME-ACCURATE ADAPTIVE SECOND-ORDER UPWIND SCHEMES
- STANDARD & EXTENDED k-ε TURBULENCE MODELS WITH COMPRESSIBILITY CORRECTIONS
- MULTI-ZONE BODY-FITTED FORMULATIONS

- EULERIAN/LARGRANGIAN MULTI-PHASE SOLUTION METHOD FOR MULTI-ZONE MESH
- TURBULENCE/PARTICLE INTERACTION MODEL
- PENALTY FUNCTION CORRECTED EFFICIENT FINITE-RATE CHEMISTRY INTEGRATION METHOD
- HERMSEN CORRELATION EMPLOYED FOR THE AL PARTICLE COMBUSTION RATE

Turbulent Dispersion

The random turbulent velocity components were assumed to have Gaussian probability distribution with standard deviation equal to $(2k/3)^{1/2}$. Similar techniques have been used by, for example, Dukowicz and Gosman and Ioannides. The turbulent velocity components are thus computed using

$$u' = (4k/3)^{1/2} \, \mathrm{erf}^{-1}(2x-1)$$

where x is a random variable with uniform probability distribution between 0 and 1. The generated turbulent velocity components are added to the mean velocity field of the continuous phase in evaluating the interphase drag force.

ASRM APPLICATION -- CURRENT STATUS

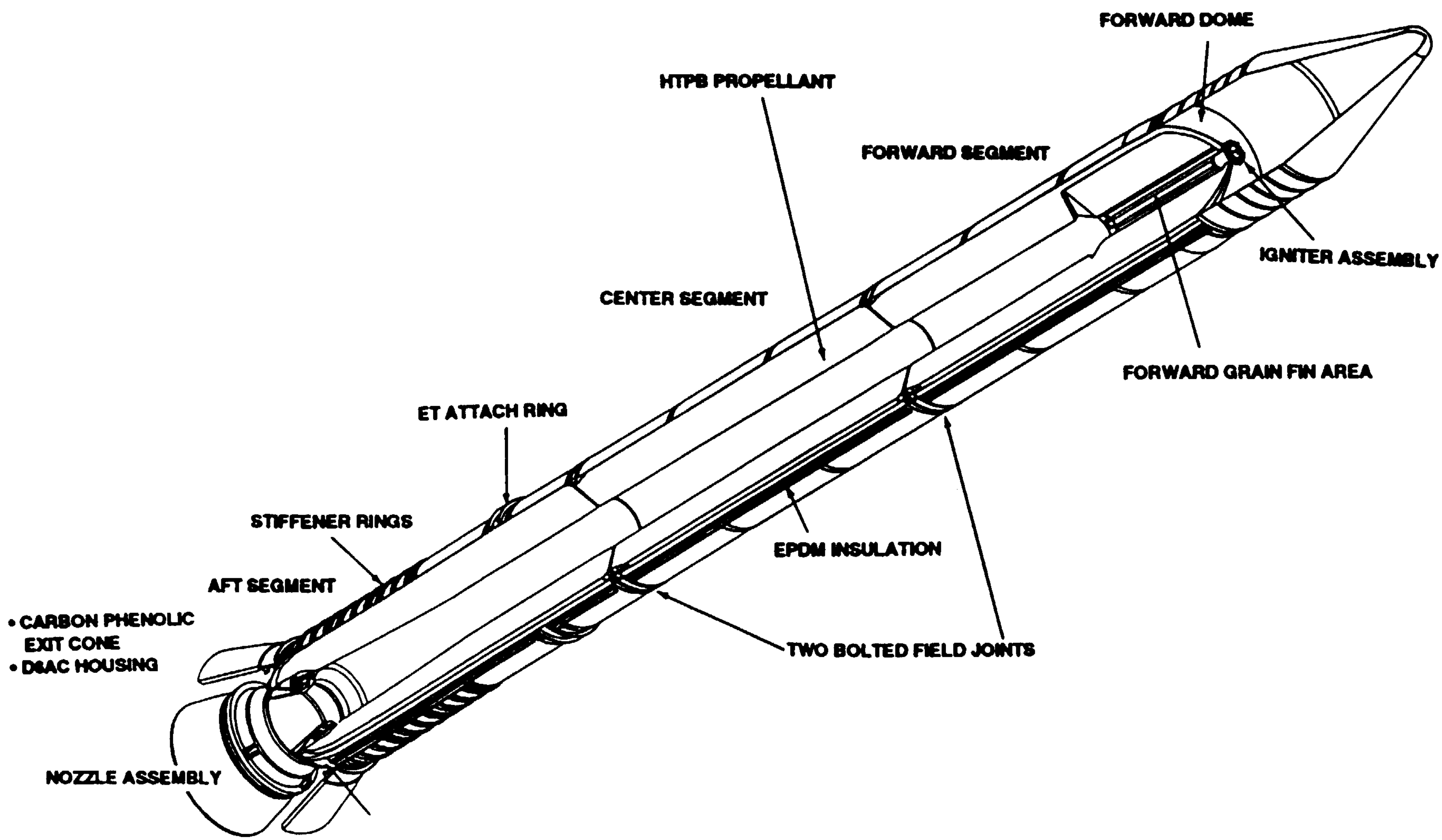
- MODELS:

  1. 3-ZONE 2-D GEOMETRY (INCLUDING CHAMBER, AFT-END CAVITY, AND SUBMERGED NOZZLE)
  2. 6-ZONE 3-D GEOMETRY (INCLUDING CHAMBER, AFT-END CAVITY, SUBMERGED NOZZLE, INHIBITORS, AND GRAIN PORT)

- SIMULATION OF STEADY-STATE FLOW FIELD AT LAUNCH CONDITION

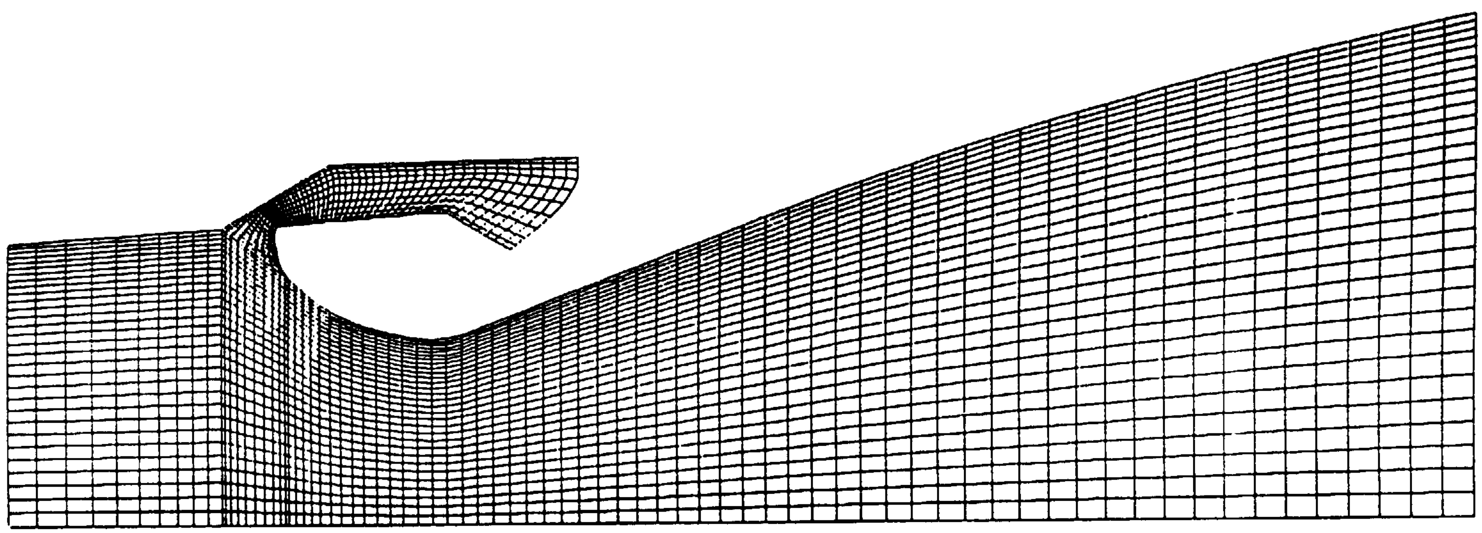
Engineering Sciences, Inc.

THE ASRM

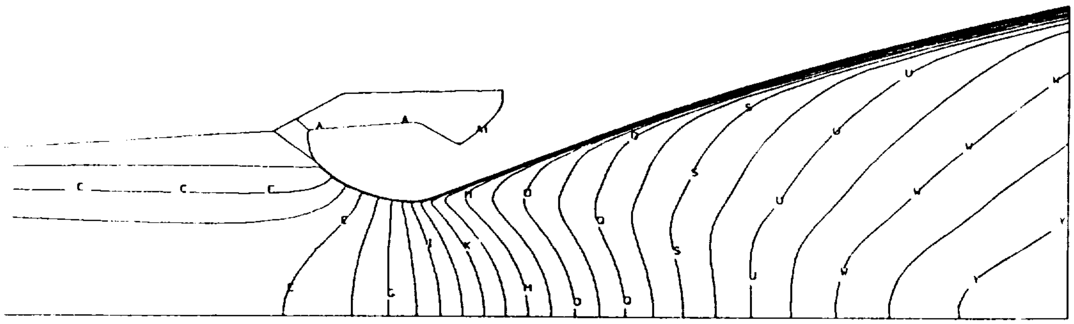


ESI Engineering Sciences, Inc.

2-D GRID SYSTEM

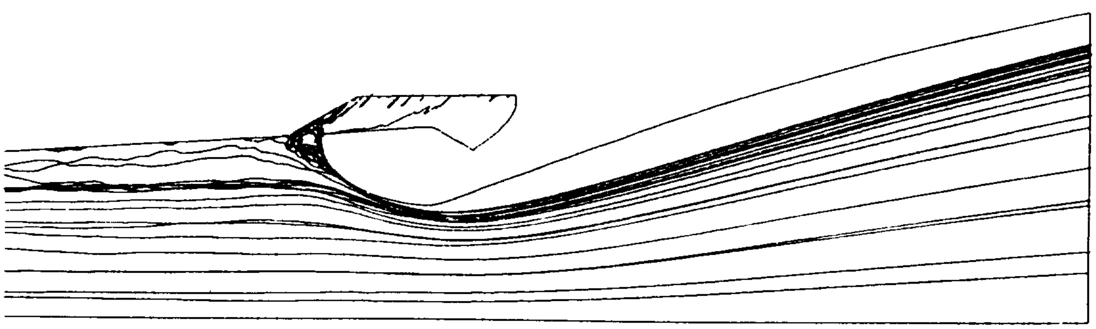


ESI Engineering Sciences, Inc.

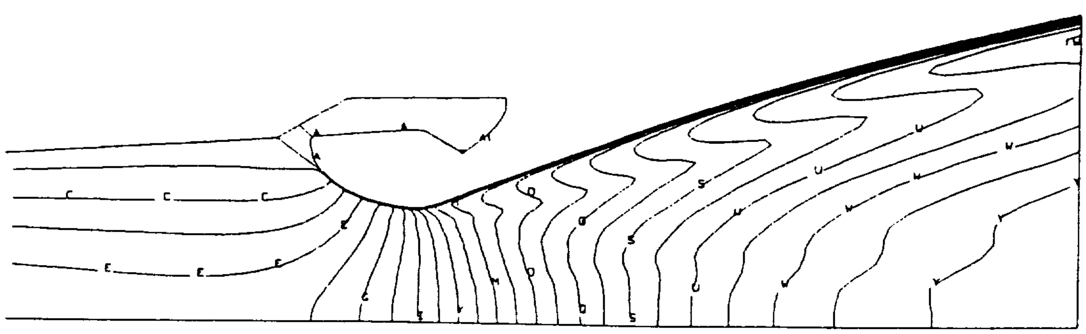


CONTOUR LEVELS	
ID	VALUES
A	0 0000E+00
B	1 4028E-01
C	2 8057E-01
D	4 2086E-01
E	5 6114E-01
F	7 0143E-01
G	8 4172E-01
H	9 8200E-01
I	1 1222E+00
J	1 2625E+00
K	1 4028E+00
L	1 5431E+00
M	1 6834E+00
N	1 8237E+00
O	1 9640E+00
P	2 1043E+00
Q	2 2445E+00
R	2 3848E+00
S	2 5251E+00
T	2 6654E+00
U	2 8057E+00
V	2 9460E+00
W	3 0863E+00
X	3 2265E+00
Y	3 3668E+00
Z	3 5071E+00

MACH NUMBER DISTRIBUTIONS NEAR THE NOZZLE (WITHOUT PARTICLE EFFECT)

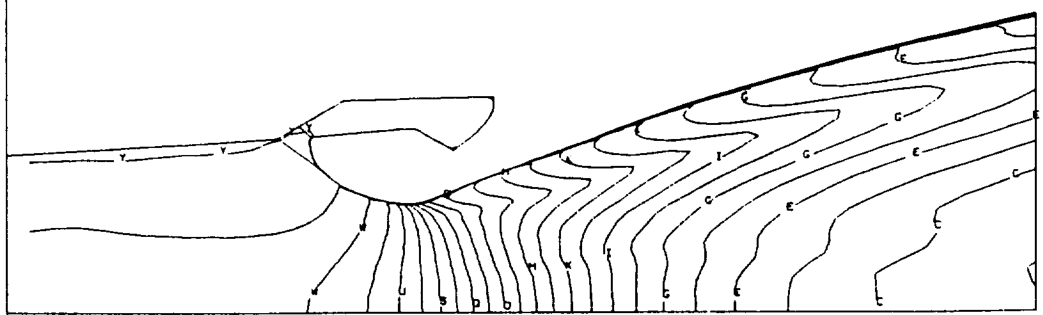


PARTICLE DISTRIBUTIONS NEAR THE NOZZLE



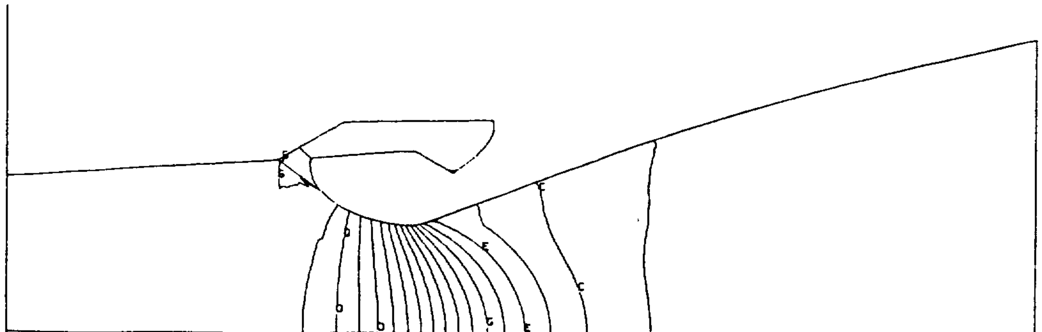
CONTOUR LEVELS	
ID	VALUES
A	0 0000E+00
B	1 1885E-01
C	2 3770E-01
D	3 5655E-01
E	4 7540E-01
F	5 9425E-01
G	7 1310E-01
H	8 3195E-01
I	9 5080E-01
J	1 0696E+00
K	1 1885E+00
L	1 3073E+00
M	1 4262E+00
N	1 5450E+00
O	1 6639E+00
P	1 7827E+00
Q	1 9016E+00
R	2 0204E+00
S	2 1393E+00
T	2 2581E+00
U	2 3770E+00
V	2 4958E+00
W	2 6147E+00
X	2 7335E+00
Y	2 8524E+00
Z	2 9712E+00

MACH NUMBER DISTRIBUTIONS (WITH PARTICLE EFFECT)



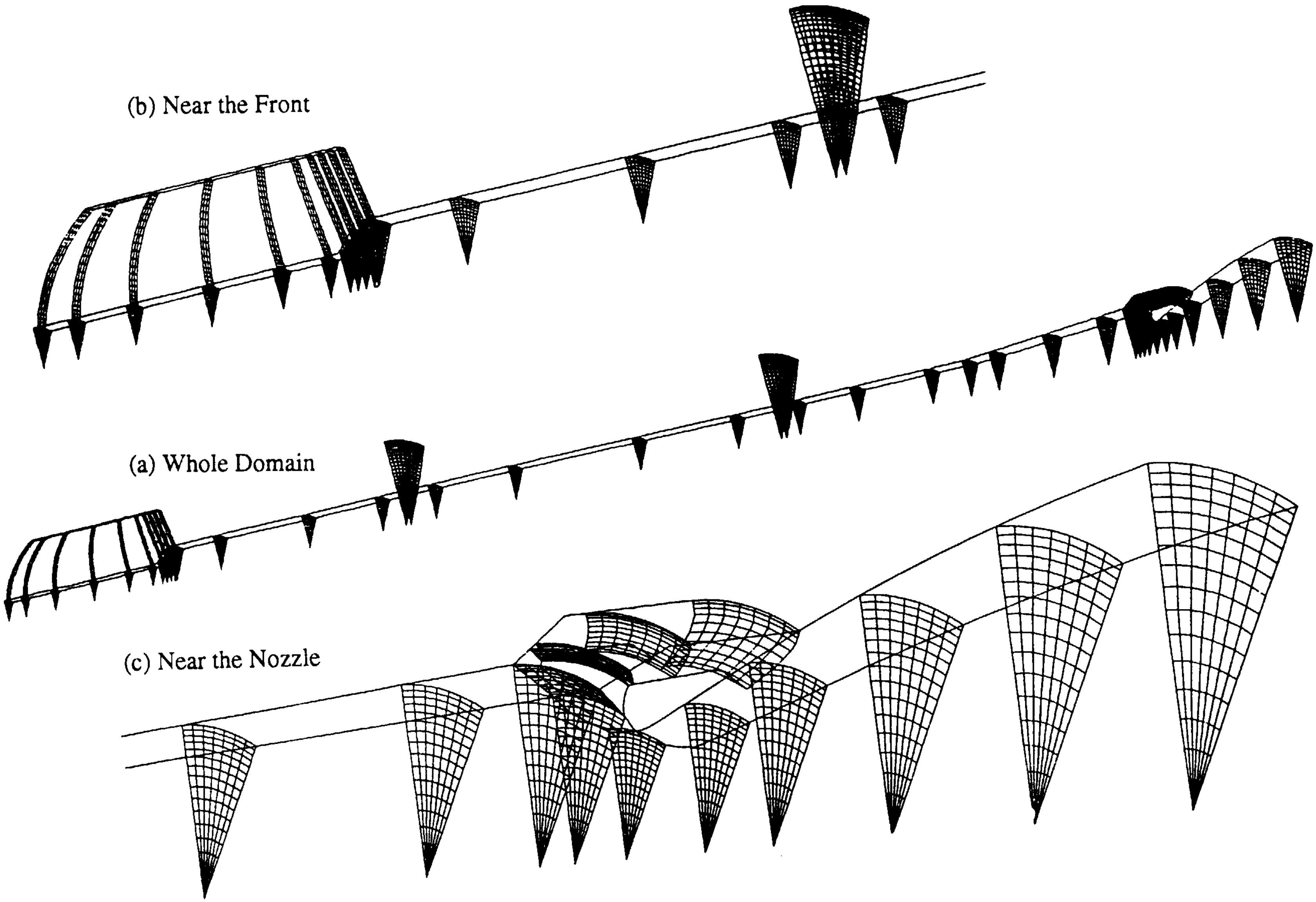
CONTOUR LEVELS	
ID	VALUES
A	1 4698E+03
B	1 5513E+03
C	1 6329E+03
D	1 7144E+03
E	1 7959E+03
F	1 8774E+03
G	1 9590E+03
H	2 0405E+03
I	2 1220E+03
J	2 2035E+03
K	2 2851E+03
L	2 3666E+03
M	2 4481E+03
N	2 5296E+03
O	2 6112E+03
P	2 6927E+03
Q	2 7742E+03
R	2 8557E+03
S	2 9373E+03
T	3 0188E+03
U	3 1003E+03
V	3 1818E+03
W	3 2634E+03
X	3 3449E+03
Y	3 4264E+03
Z	3 5079E+03

TEMPERATURE DISTRIBUTIONS (WITH PARTICLE EFFECT)

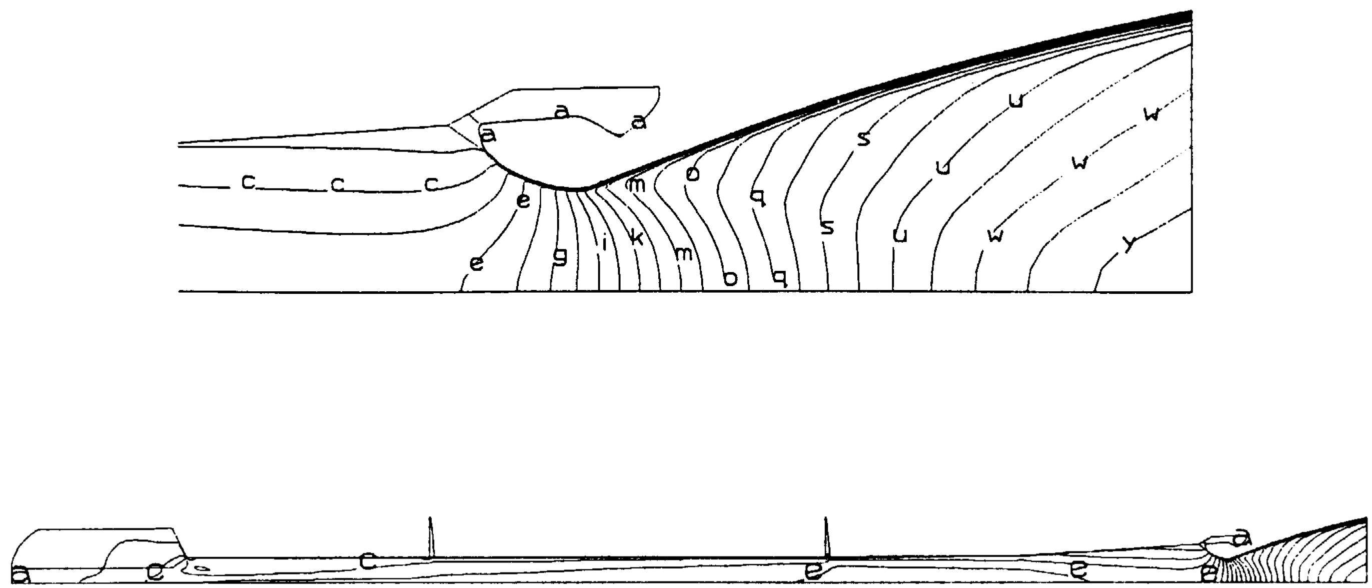


CONTOUR LEVELS	
ID	VALUES
A	1 4183E+00
B	6 2819E+00
C	1 1145E+01
D	1 6009E+01
E	2 0872E+01
F	2 5736E+01
G	3 0599E+01
H	3 5463E+01
I	4 0326E+01
J	4 5190E+01
K	5 0053E+01
L	5 4917E+01
M	5 9781E+01
N	6 4644E+01
O	6 9508E+01
P	7 4371E+01
Q	7 9235E+01
R	8 4098E+01
S	8 8962E+01
T	9 3826E+01
U	9 8689E+01
V	1 0355E+02
W	1 0841E+02
X	1 1328E+02
Y	1 1814E+02
Z	1 2300E+02

PRESSURE DISTRIBUTIONS (WITH PARTICLE EFFECT)



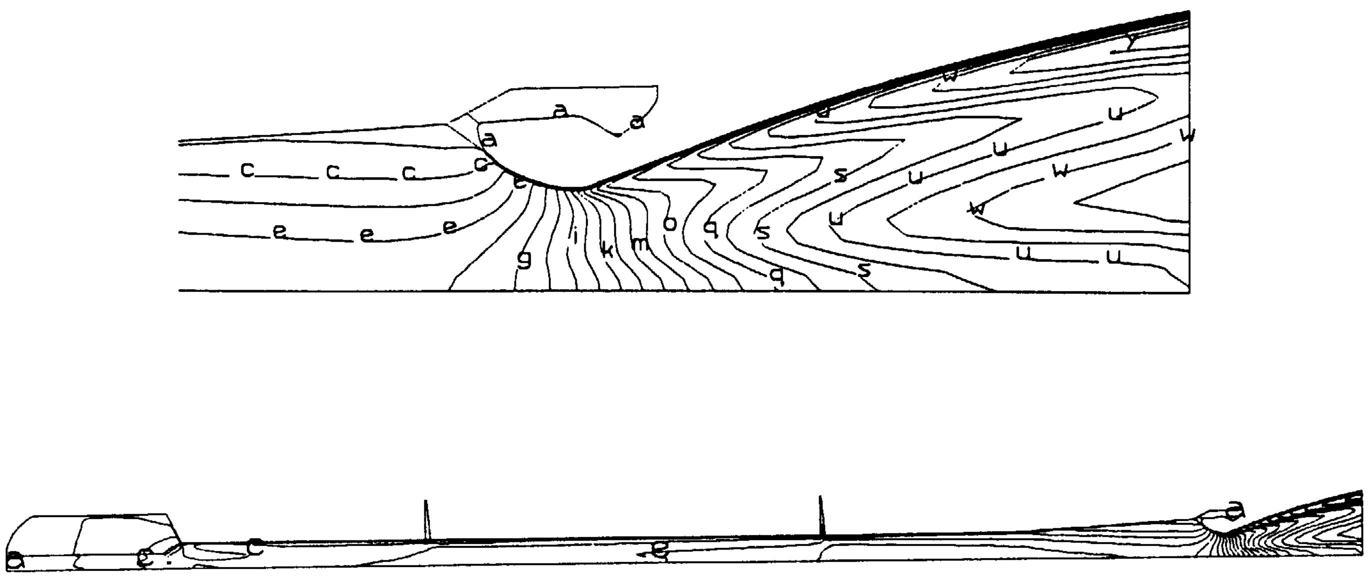
3-D GRID SYSTEM



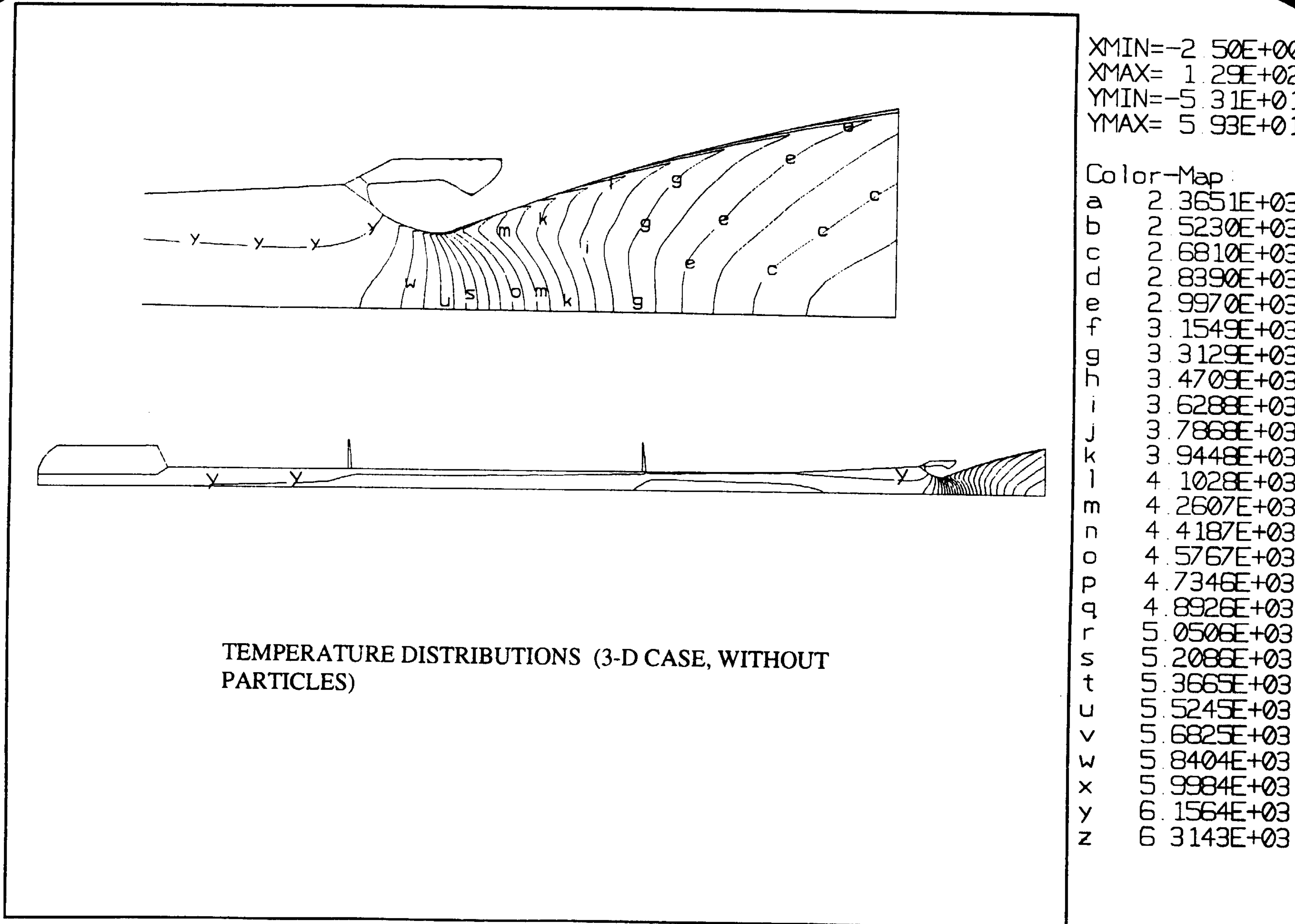
MACH NUMBER DISTRIBUTIONS (WITHOUT PARTICLES)

PARTICLE DISTRIBUTIONS

ESI Engineering Sciences, Inc.

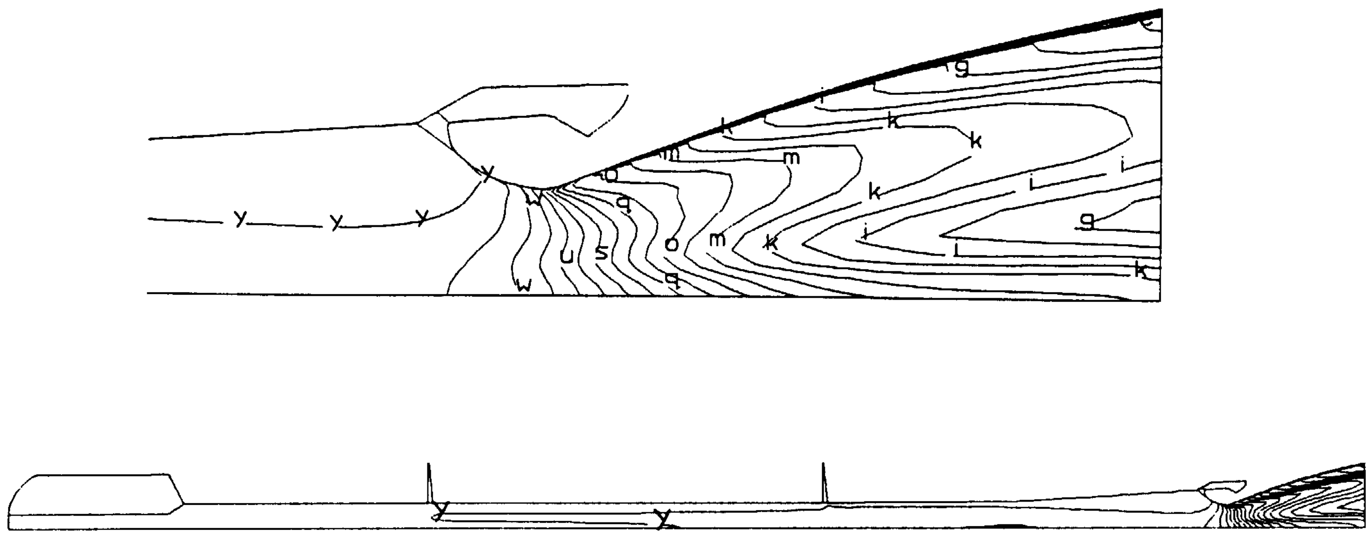


MACH NUMBER DISTRIBUTIONS (WITH PARTICLES)



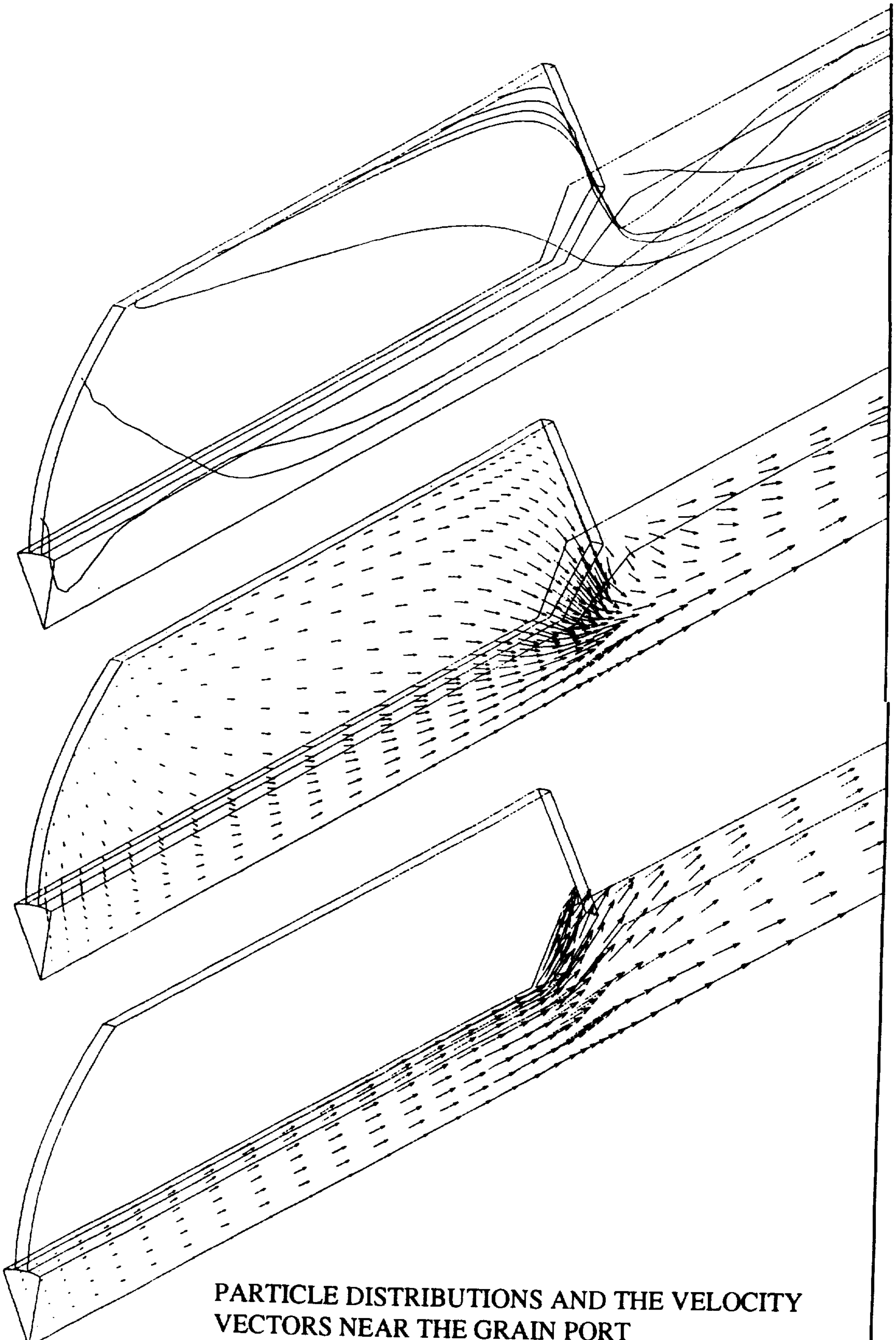
TEMPERATURE DISTRIBUTIONS (3-D CASE, WITHOUT PARTICLES)

ESI Engineering Sciences, Inc.

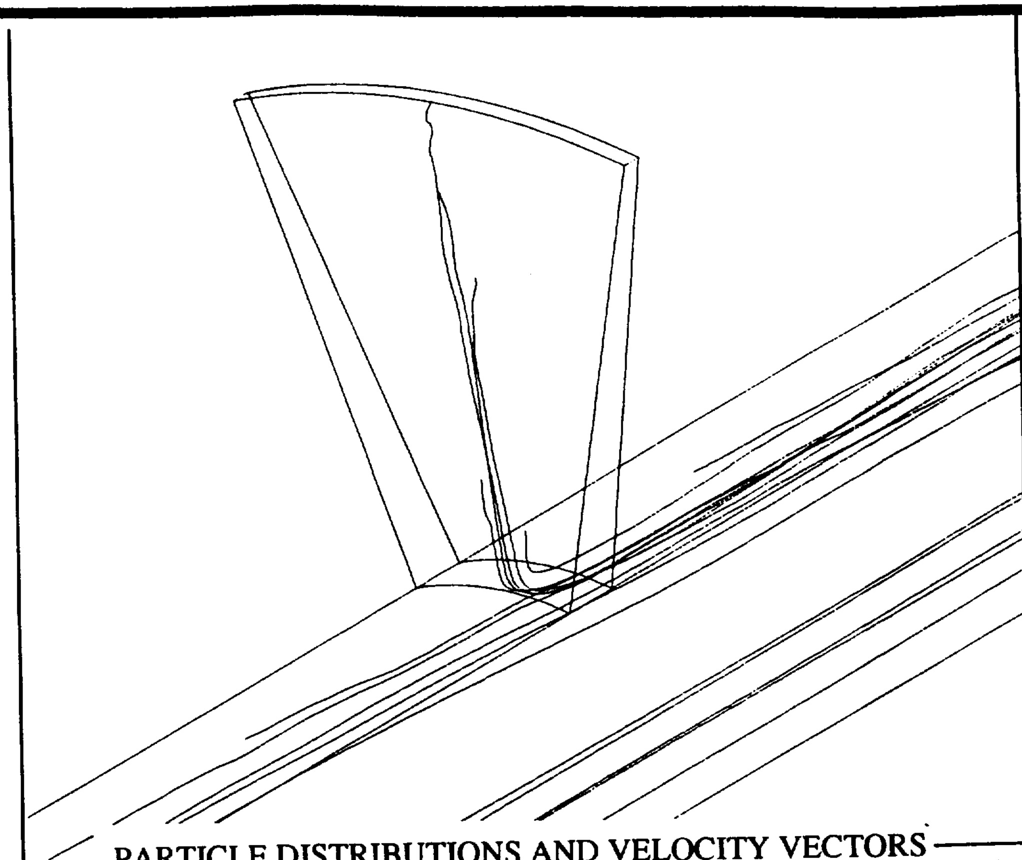


TEMPERATURE DISTRIBUTIONS (3-D CASE, WITH PARTICLES)

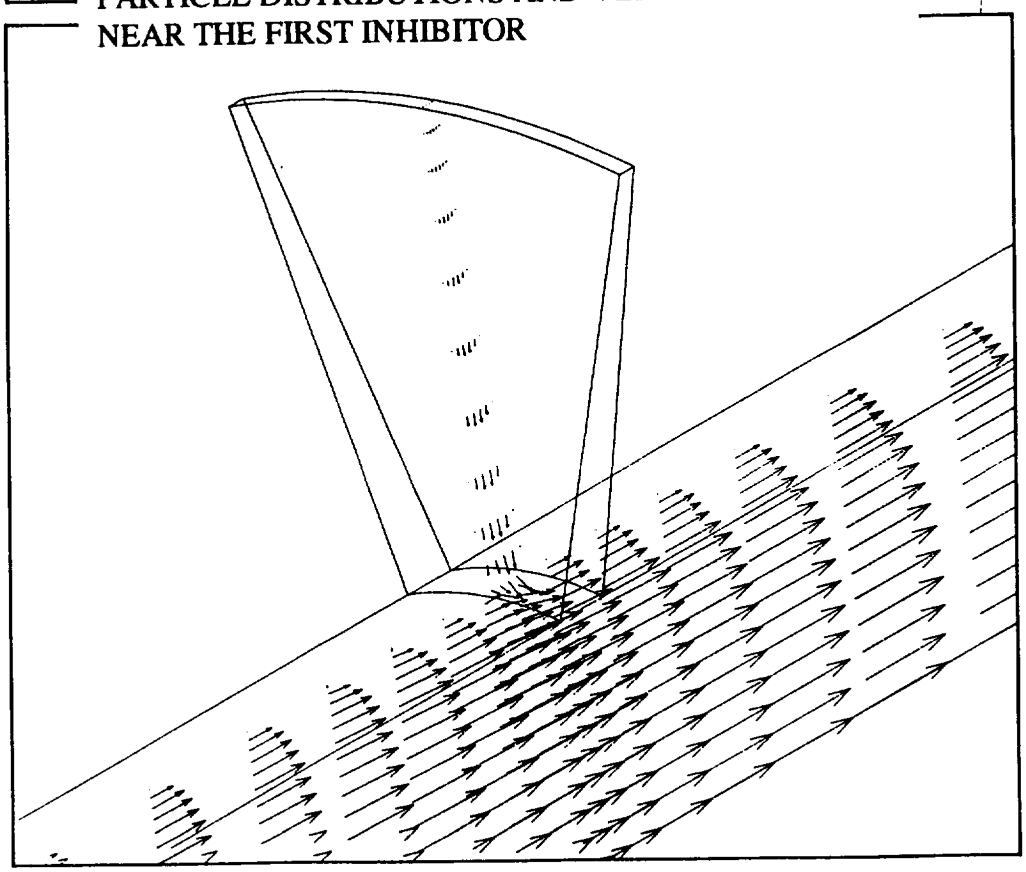
ESI Engineering Sciences, Inc.

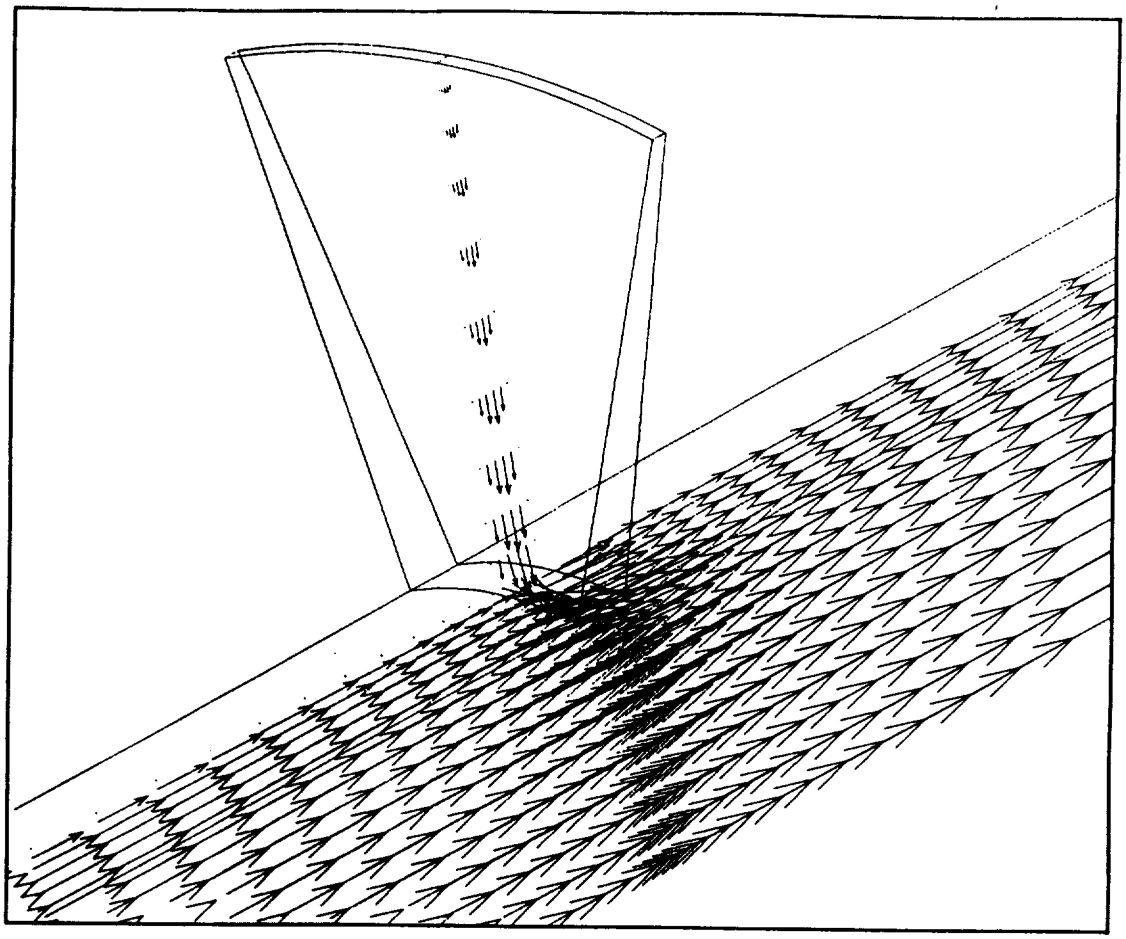


PARTICLE DISTRIBUTIONS AND THE VELOCITY VECTORS NEAR THE GRAIN PORT

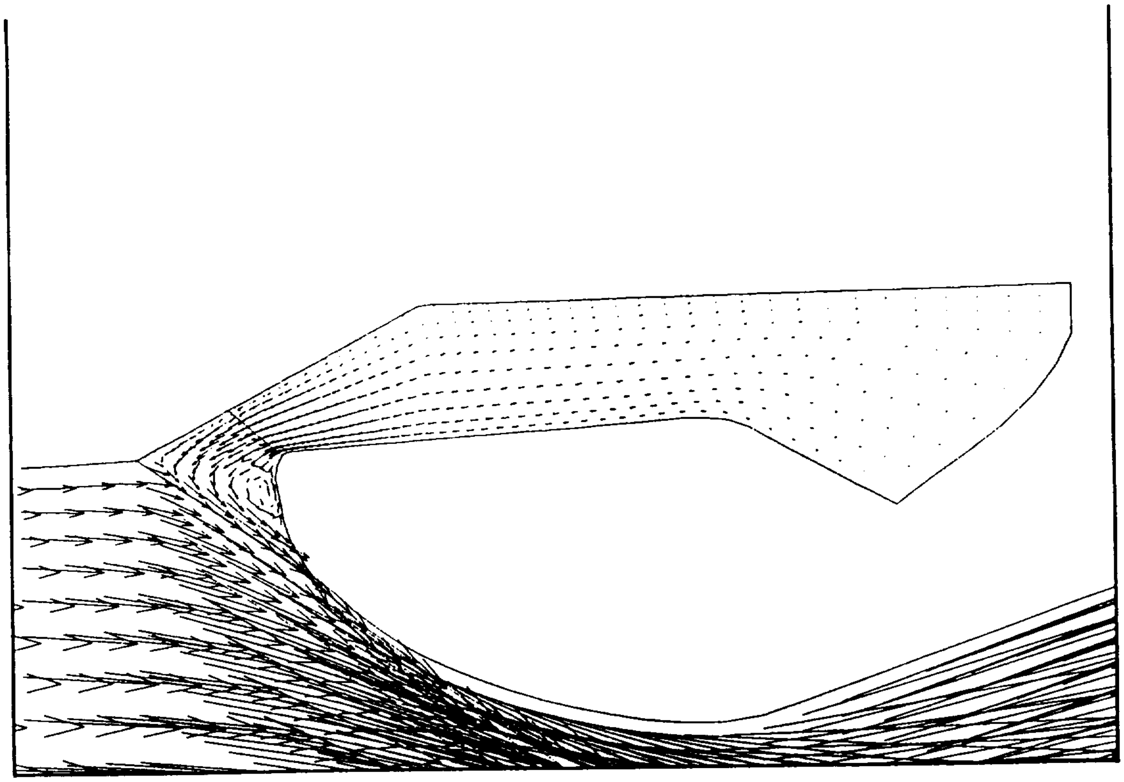


PARTICLE DISTRIBUTIONS AND VELOCITY VECTORS
NEAR THE FIRST INHIBITOR

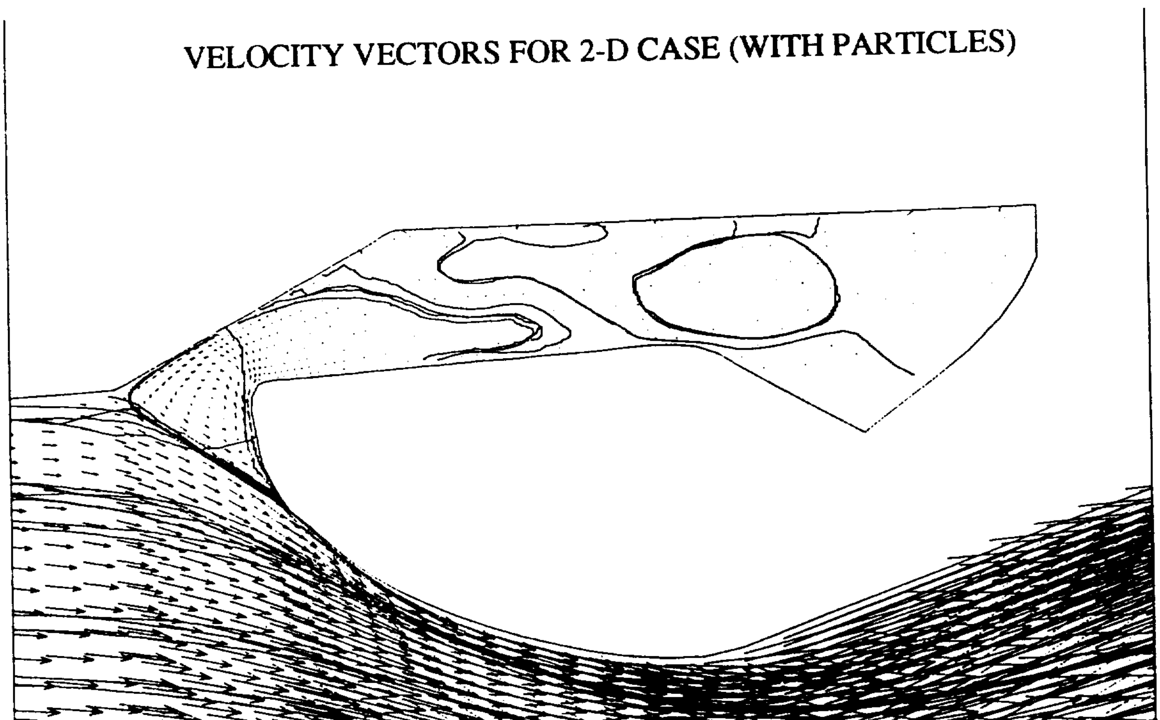




VELOCITY VECTORS NEAR THE SECOND INHIBITOR



VELOCITY VECTORS FOR 2-D CASE (WITH PARTICLES)



PARTICLE DISTRIBUTIONS AND VELOCITY VECTORS
FOR 3-D CASE (WITH PARTICLES)

PARTICLE TRAJECTORIES NEAR THE NOZZLE, 3-D CASE.

CONCLUSIONS

1. THE FDNS CODE SUCCESSFULLY PREDICTED THE MULTI-PHASE FLOW SIMULATION OF THE ASRM WITH CHEMICAL REACTION AND TURBULENT PARTICLES. THE COMPUTED FLOW FIELD IS REASONABLE BASED ON THE KNOWN DATA AND THE PHYSICAL POINT OF VIEW.

2. THE RECIRCULATION ZONE AT THE ENTRY OF THE AFT-END CAVITY IS PREDICTED CORRECTLY. MORE INVESTIGATIONS SHOULD BE DONE FOR FURTHER EVALUATION OF THE EFFECT ON THE PERFORMANCE OF ASRM DUE TO THE RECIRCULATION ZONE.

FOLLOWING WORK

- GENERATE AL AGGLOMERATE SIZE INITIAL CONDITIONS TREATMENT
- INVESTIGATE THE PARTICLE COMBUSTION AND COLLISION/BREAKUP MODELS FOR BENCHMARK TESTING CASES (NAVAL POST-GRADUATE DATA, FRENCH DATA, ETC.)
- INVESTIGATE THE EFFECT OF PARTICLE DEPOSITION ON THE CHAMBER WALL (MOVING BOUNDARY SCHEME WILL BE TESTED)

ESI Engineering Sciences, Inc.